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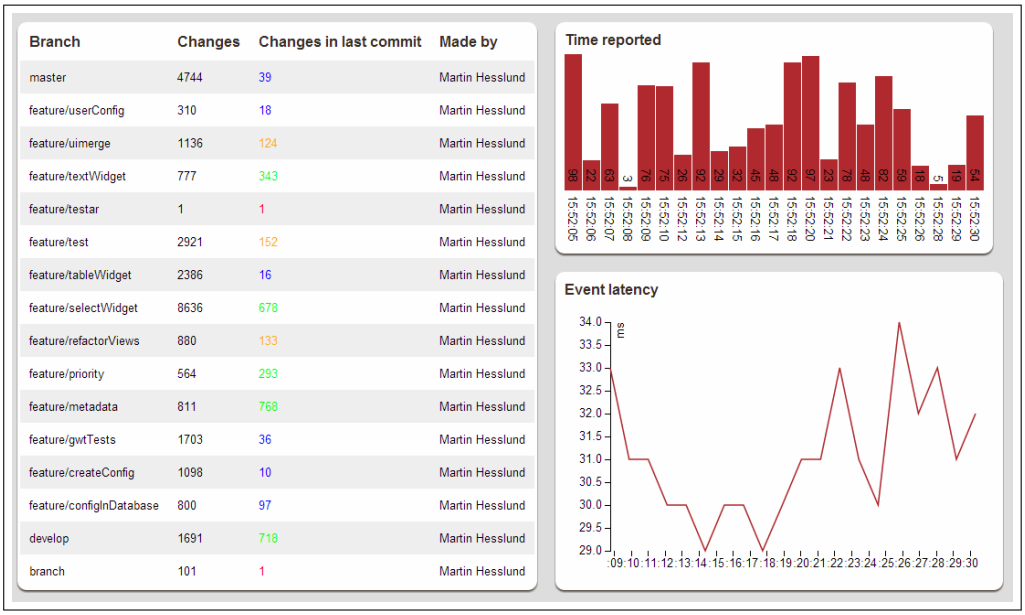

Web-based Real-time Information Dashboard

An event-driven approach to visualize telemetry data

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Dashboard

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Abstract

Traditional information dashboards where data are updated at fixed intervals or on user interaction do not fulfill all needs for software development practitioners. There is a need for access to information in real-time in order to support decisions in an ever-changing reality.

The research presented in this thesis was conducted during 6 months, using a design science research methodology, with the industrial partner Surikat. Part of the study is interviews with three employees at Surikat as well as quantitative performance measurements on a proof-of-concept system developed during the thesis.

The proof-of-concept was realized with an event-driven architecture using WebSocket for communication between server and client. Performance measurements revealed that the system gives an average round-trip time, RTT, of 5066ms across all tests. The tests ranged from 1 client and 1 message per second to 50 clients and 80 messages per second, with and without aggregations on the server. The test also showed there are significant difference between browsers. The average RTT was 1640ms for Chrome and 17285ms for Internet Explorer.

The proof-of-concept developed during this thesis shows that it is possible to create real-time information dashboards using open source frameworks and emerging web technologies, such as WebSocket. The performance tests show that the system copes well compared to the requirements developed with Surikat but that there are significant differences between older and newer browsers. In addition, interviews revealed that real-time updates give project managers support to make faster decisions.

Acknowledgements

We would like to thank Surikat for giving us the opportunity to do this thesis. We are especially thankful to all interviewees and our supervisor at Surikat who helped us throughout the study with valuable feedback. We would also like to thank Associate Professor Miroslaw Staron, Chalmers University of Technology, who guided us through this thesis.

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Contents

1 Introduction

Different stakeholders in software projects have different information needs. Developers want to see detailed information of the development progress and project managers want to see the overall status of the projects (Buse & Zimmermann 2012). A common way to show this information is to use information dashboards (Jakobsen et al. 2009) (Treude & Storey 2010) (Kobielus et al. 2009). To be able to satisfy the different needs, a dashboard must be highly customizable with respect to information source and how it is displayed.

Traditionally, information dashboards visualize data collected from systems at regular intervals such as every day or hour, which is not fast enough (Johnson 2007) (Treude & Storey 2010). The constantly changing reality of software development demands a new way to approach software monitoring where the information is up-to-date all the time. A more event-driven approach is needed, where the information visible to the user is updated within seconds of the availability of new data (Levina & Stantchev 2009).

Thanks to the evolution of handheld devices, stakeholders want to have instant access to information everywhere. Not only on their handheld devices but on whatever device, such as computers, phones, tablets and information radiators (Whitworth & Biddle 2007), they currently have access to. With all these devices, there are large differences in operating system, screen size and especially performance (Wang et al. 2011). To avoid costly development of several different tools, it is desirable for a single solution to work across the segmented landscape. One way to address this problem is to use web technologies, which are available on all major platforms (Charland & LeRoux 2011).

One large obstacle encountered when trying to achieve continuous updates using web technologies is that these technologies are generally not well suited for this type of usage. Traditional web communications are not constructed to handle communication initiated by the server (Bozdag et al. 2007). Recent developments have however made efforts to improve this by introducing WebSocket giving a significantly better performance than traditional web communications (Agarwal 2012).

By using recent technological advancements in the area of real-time web communications, this thesis suggests that information dashboards can be improved by providing faster information updates. This presents a few challenges:

- What are suitable real-time requirements for information dashboards?
- How to achieve these requirements on mobile and regular clients.
- Whether real-time updates are necessary for all information.
- What benefits real-time information provides in dashboards.

1.1 Scope and limitations

The scope and limitations of this thesis are the following.

- This study has focused on real-time computing from a software and web application perspective. This is due to lack of control over hardware when dealing with Internet connections and consumer devices as well as the need for a single solution for multiple environments.
- Only solutions that work in a web-based environment without third party plugins, such as flash, have been examined as not all devices have support for such plugins (Vaidya & Naik 2013).
- This study only includes one case, Surikat. The extent of the study was limited due to the short duration, less than 6 months, of the master's thesis.

1.2 Contribution and thesis structure

Chapter 2 describes earlier work with dashboards, software project measurements and introduces the web technologies that make real-time web applications possible. Chapter 3 presents the research questions and covers the methodology used for the thesis. Chapter 4 covers the architecture of the proof-of-concept solution as well as presents the results from qualitative and quantitative studies conducted. Chapter 5 discusses the findings. Chapter 6 provides the conclusions, limitations and future work of this thesis.

2 Background

The background for this thesis can be divided into three areas. Firstly, the theoretical framework that explains the theories this thesis is built upon is explained. Secondly, other studies of similar products are covered and lastly, the technologies that make real-time web applications possible are presented. These three background areas and their main content are shown in figure 2.1.

2.1 Theoretical framework

This section discusses different areas that offer principles applicable to information dashboards.

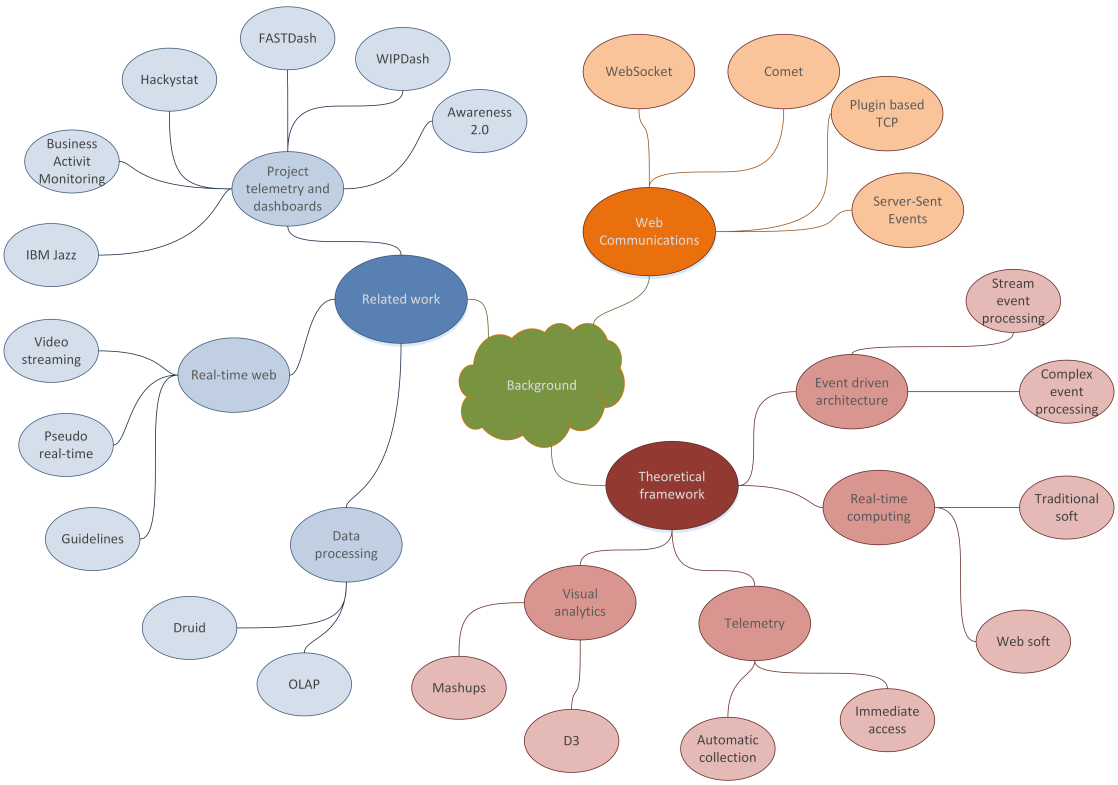

Figure 2.1: Mind map of the background study

2.1.1 Real-time computing

Real-time systems are described by Stankovic et al. as systems that not only depend on the correctness of the execution, but also the time it takes to perform those executions (1992). Common for all real-time systems is the presence of an execution deadline. There are three classes of real-time systems that define the value of the information after the execution deadline (Shin & Ramanathan 1994).

- Hard – Not meeting the deadline can have catastrophic consequences.
- Firm – The information is useless after the deadline.
- Soft – Information decreases in value after the deadline but is still useful.

A system is not real-time just because a component is real-time; all parts of the system need to meet the time constraints. This makes it hard to create real-time systems that communicate over the Internet. Due to lack of the concept of predictable deadlines in the TCP protocol, real-time computing in the traditional sense is impossible (Gamini Abhaya et al. 2012). This means that while a true real-time system can know in advance whether a request will be fulfilled before its deadline, web-based systems can only know after the request is processed if it met its deadline. Since there is no guarantee that the message is received by the client at all (Xiao & Ni 1999), it is not suitable to have hard real-time in web-based systems.

2.1.2 Event-driven architecture

Systems that are progressed by notable things happening can be designed by following an event-driven pattern (Michelson 2006).

Events are uniquely identifiable and each contains the source of the event, a timestamp as well as an event body. The event body must be predefined in such a way that all consumers of the event know how to process it. Events can be generated both outside and inside the system. Event-driven architectures are highly decoupled where event generators have no knowledge of what happens to an event after it has been generated (Michelson 2006).

Events are often processed after they are collected. There are three styles for event processing: simple event processing, stream event processing, and complex event processing.

Simple event processing is the most basic one and consists of an event triggering an action downstream in the event chain.

Stream event processing is slightly more involved than simple event processing. Data is filtered and only forwarded to subscribers of that information. Stream event processing does, as simple event processing, only deal with one event at the time.

With complex event processing, it is possible to look at events in a context. This enables the system to take actions based on multiple events across a span of time, different event sources or other relations (Michelson 2006).

It is also possible to combine event-driven architecture with service-oriented architecture, SOA. This reduces the coupling further as the usage of web services removes some of inflexibility in other solutions; such as remote procedure call based ones (Levina & Stantchev 2009).

2.1.3 Telemetry

Telemetry is the broad term describing highly automated collection of measurements from a distance (Telemetry 2013). Telemetry can be applied in a number of areas. The areas of interest here are the collection of data and measurements from other software systems for example project management systems or any other enterprise system core to company operations. Data is generally gathered by small add-ons in these systems.

Software project telemetry is defined by Johnson et al. (2005) as having five characteristics:

- "The data is collected automatically by tools that regularly measure various characteristics of the project development environment."
- "The data consists of a stream of timestamped events where the time-stamp is significant for analysis."
- "Both developers and managers can continuously and immediately access the data."
- "Telemetry analyses exhibit graceful degradation."
- "Analysis includes in-process monitoring, control, and short-term prediction."

This type of metric gathering is very flexible and can be adjusted to work well in most projects, as it requires little effort to collect the data. This could be especially well suited for agile development as it gives frequent and continuous measurements and allows for fast feedback on decision making (Johnson et al. 2005).

2.1.4 Visualization

Using visualizations to provide more understanding when working with large data sets is widely recognized within the sciences (Keim et al. 2006). The use of visualizations in the field of business intelligence, BI, has gained a lot of popularity and various visualizations are now commonplace in various BI tools.

This thesis focuses on web-based technologies and that introduces some limitations regarding visualization. Most important is compatibility with most browsers. This generally means adherence to the HTML5 standard[1]. The JavaScript library Data-Driven Documents[2], D3 for short, offers a transparent and simple way to create scalable vector graphics, SVG[3], (Bostock et al. 2011).

[1] http://www.w3.org/TR/html5/
[2] http://d3js.org/
[3] http://en.wikipedia.org/wiki/Svg

In modern companies, not all data is located in a single service making it cumbersome to look at relationships between data from different services. To solve this problem, some research has gone into the field of enterprise mashups (Pahlke et al. 2010). The term 'mashup' has its roots in consumer web services that aggregate content, and sometimes layout, from other services. Enterprise mashups are constructed in a similar fashion but generally only aggregate services from a company's intranet (Pahlke et al. 2010). Enterprise Mashups can be categorized by their complexity from just displaying user interface elements from different services to creating workflows from different components.

Enterprise mashups are in many ways related to business intelligence dashboards. One of the many uses for mashups is to create dashboards where the user is free to customize the functionality without support from IT professionals (Kobielus et al. 2009).

2.2 Related work

In this section, previous work in the area of real-time computing for the web, several tools that use dashboards to display data as well as techniques used to process and visualize data are presented.

2.2.1 Real-time computing for the web

This section summarizes results from three related studies that involve real-time computing for web. These studies try to solve the problem at the end systems, server and client. This is the easiest part to solve since it is the only one under complete control without making changes to the Internet infrastructure.

Wu et al. (2000) identified four problems when sending real-time video on the Internet. These four problems are bandwidth, delay, loss and heterogeneity. They present a framework that handles the problems at the end systems. The framework consists of two components: congestion control and error control.

Another solution for real-time video over the Internet is to send the information over UDP, which allows the server to control the frame size and rate. The client informs the server if a frame is lost or did not meet the deadline so that the server can change the frame size and rate to the client (Hsiao et al. 2012). When showing live video, frames that arrive after their viewing time do not add any value. Thus the server never re-sends frames; this type of behavior belongs to the firm real-time systems.

Gamini Abhaya et al. (2012) have provided a set of guidelines for developing a web-based real-time middleware. To get predictable execution times in the middleware, all the lower levels of the program need to support predictable executions, that means that the operating system as well as the programming language have to support it.

2.2.2 Telemetry and dashboards

Recent research in the area of software project telemetry has resulted in a few tools.

One tool that specializes in software engineering process telemetry is Hackystat. Hackystat did not support real-time updates of data through server pushes as of 2006

(Keim et al. 2006). Hackystat's architecture has since been completely redesigned using a service-oriented approach (Johnson et al. 2009) and now supports near real-time updates through polling.

Another tool is FASTDash, which helps development teams to know what files that are currently being worked on. The information is presented in widgets on a dashboard that is displayed on a large shared screen or on each developer's computer (Biehl et al. 2007).

Similar to FASTDash is WIPDash, which is a dashboard that visualizes the overall status of a project on a large shared display. This system differs from FASTDash by supporting interaction from the user. For example, it is possible to click on a team member and see all work items assigned to that team member. The information on the display is updated once per minute by querying the server (Jakobsen et al. 2009).

To examine how dashboards are used to improve awareness in software engineering projects, Treude & Storey (2010) studied software teams using IBM Jazz in their development processes. In addition to dashboards, Jazz also includes feeds showing events. The study found that it is important to address awareness on both a high and low level.

Information dashboards are also used outside the field of software engineering. There exist several commercial and open-source tools for real-time monitoring of business processes. These systems are generally referred to as Business Activity Monitors. Some of the software giants have their own propriety systems[4][5][6]. There also exist a couple of open-source alternatives, such as WSO_2 Business Activity Monitor[7]. These systems are all integrated with other systems from the same vendor, which makes them less flexible.

2.2.3 Visualization Systems

There exist several types of visualization systems. The ones that are most interesting in our case are the programming toolkits, which are popular for presenting live data. Google Chart[8], Highcharts[9] and JFreeChart[10] are examples of toolkits that have a limited number of chart types that the user can choose from.

For users that want to be able to add new chart types and other types of visualization, tools like Protovis (Bostock & Heer 2009) and D3 (Bostock et al. 2011) are a better solution. Both tools allow the user to create any type of visualization with the tools' JavaScript API. The downside is that it is harder to get started since the learning curve is steeper. However, the learning curve is even steeper for learning the different SVG APIs of all browsers (Bostock et al. 2011).

[4]http://www-01.ibm.com/software/integration/business-monitor/
[5]http://www.microsoft.com/biztalk/en/us/business-activity-monitoring.aspx
[6]http://www.oracle.com/technetwork/middleware/bam/overview/index.html
[7]http://wso2.com/products/business-activity-monitor/
[8]https://developers.google.com/chart/
[9]http://www.highcharts.com/
[10]http://www.jfree.org/jfreechart/

2.2.4 Data processing

To display more interesting information than simple raw data, some sort of data processing is necessary. Following are a few alternatives.

Firstly, Druid is a "real-time" analytical data storage that consists of 4 types of nodes that together make the Druid cluster. The four different types are:

- *Real-time node* receives the data stream and makes it available for real-time queries; the information is stored in memory.
- *Historical node* stores segments, Druid's fundamental storage unit, in the permanent storage as well as exposing them for querying.
- *Broker node* knows what segments exists and on which nodes they are stored. It also handles the incoming queries and routes them to the correct nodes.
- *Coordination or master node* is responsible for all segment management, loading new segments, dropping outdated segments, segment replication and balancing segment load.

Druid does not use SQL as its querying language; it has instead developed its own querying language that is based on JSON, JavaScript Object Notation (Yang et al. 2013).

When the thesis started, Druid only had support for permanent storage in Amazon S3. Since the information shown by systems like dashboards can be company secrets the option for running the database on private servers is necessary.

Secondly is OLAP, on-line analytical processing (Codd et al. 1993). It is a framework for making complex statistical calculations, such as moving average and drill-downs, where the data is often represented as a multidimensional cube. There are three main approaches that support OLAP queries: Relational, Multidimensional and Hybrid OLAP (Chaudhuri et al. 2001). To get a quick query response the data cube needs to be configured and precomputed (Harinarayan et al. 1996). Examples of products that implement OLAP are Mondrian[11] and IBM Cognos TM1[12].

2.3 Available technologies

One problem often encountered when creating web applications is when the server has new information it wants to push to the client. This has not been possible since web clients do not have a permanent connection to the server. Push communication has so far been implemented in web clients by performing so called long polling. Long polling works by opening a connection and keeping it alive until the server returns data. When data is received, the connection is closed and a new connection is established.

[11] http://mondrian.pentaho.com/
[12] www.ibm.com/software/products/us/en/cognostm1

Long polling and several other techniques that use Ajax to send messages in a push like style are collected under the umbrella term Comet (Bozdag et al. 2007). All these techniques are transported on the HTTP connect and for each new message sent, a new connection has to be established. This introduces significant overhead making Comet inappropriate when sending data to clients with constraints on bandwidth, such as mobile devices (Liu & Sun 2012).

The desired way to push information is to open a TCP socket to the client, as it has less overhead in the communication between the server and the client. Web browsers do not support this by default so a browser plug-in, such as Java-applets, Adobe Flash or Microsoft Silverlight, is required for this technique. The plug-in forwards the connection to JavaScript code running as usual in the browser. The requirement of a plug-in makes this method less desirable as it is not possible to install plug-ins in all browsers (Vaidya & Naik 2013). The recent increase of security issues in mainly Java (Securelist 2013) and the hidden nature of the plug-in code may make the application appear as malware to the user, further reducing the suitability of the plug-in approach.

WebSocket is a technique that takes the advantages of socket to the web, and is supported by most web browsers (Deveria 2013*a*). It opens a persistent connection to the server over port 80, which means that it works even if the client is behind a firewall or a proxy that only allows connection over port 80. The socket allows communication both ways so that the client and the server can send messages to each other without having to reestablish a new connection after each message. Since WebSocket does not use the HTTP protocol for transmitting messages, there is less overhead on each message (Agarwal 2012). WebSocket is standardized by IETF in RFC 6455 (Fette & Melnikov 2011) and W3C is in the progress of standardizing it for web browsers. WebSocket is also under standardization for the Java platform as JSR 356 (Coward 2013).

An alternative to WebSocket is Server-sent events, SSE, which is part of the HTML5 draft. SSE allows for one-directional push communication from the server to the client over the HTTP protocol (Hickson 2012). Since the connection is one-directional, SSE does not offer any QoS and thus, it is not known to the server whether the client received the message (Hickson 2012). It is then up to the client to tell the server in the next request which is the latest received message.

3 Methodology

This chapter introduces the research questions of this thesis as well as the methodology used to answer them and in which context.

3.1 Context

This thesis was conducted in cooperation with Surikat. Surikat is an IT company that in addition to creating its own services also offers consultancy and support services. Representatives from Surikat provided requirements and insight into the problem as well as continuous feedback.

3.2 Research objective and questions

The focus of this thesis is to explore if information in real-time help with making decisions in the daily work. The goals are stated in the following research questions.

- How well does the dashboard perform against its real-time requirements?

  How many simultaneous clients can the dashboard handle and still meet the real-time requirements?

  How long time does it take from an event until the data is shown on the dashboard?

  How many events can be generated from data sources at the same time and still meet the real-time requirements?

- What technique and architecture for middleware are required for it to work on mobile devices as well as on regular clients?

- What benefits does real-time information provide in the context of dashboards?

  What information needs to be real-time?

  How do the dashboard support practitioners at Surikat in formulating decisions?

3.3 Design science research

A design science research approach as described by Vaishnavi & Kuechler (2004) was adopted for this thesis. The process is split into five major steps: awareness of the problem, suggestion, development, evaluation and conclusion. The idea is that each of these steps increases the understanding of the problem and allows for further refinement.

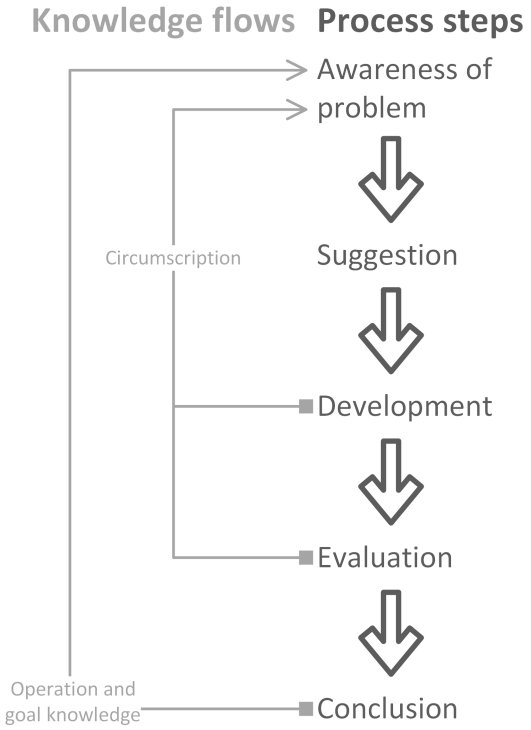

Figure 3.1: The design science research process based on image by Vaishnavi & Kuechler (2004)

The workflow of this thesis is illustrated in figure 3.2. Each column represents the different phases of the study. Rectangles represent development and study activities, hexagons represent feedback from stakeholders and ovals represent demonstrations. The different phases are described more in the following sections.

3.3.1 Awareness of the problem

Prior to the start of the thesis, Surikat had prepared a conceptual draft of how they imagined the appearance of the end result. This draft served as the basis for discussions around the requirements imposed on the system. The initial requirements were elicited through casual discussions around the system and a requirement interview with two representatives from Surikat, the representatives were a project manager with 1.5 years of experience and the company's Chief Operations Officer, COO. The interview resulted

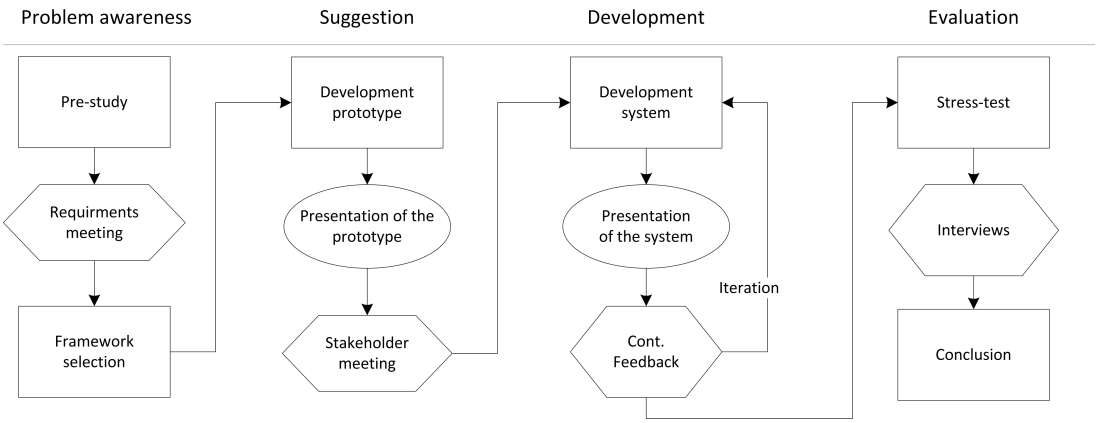

Figure 3.2: Workflow during the thesis study

in a rough set of requirements and user stories, see appendix B, which were broken down into smaller parts as they became the target of current development work. The focus of the initial requirements was to achieve a shared understanding of the quality requirements of the system and the rough outlines of its functionality.

Following is a short summary of the requirements:

- The maximum time from an event until it is shown to a user is 10 seconds.
- The average time from an event until it is shown to a user is lower than 2 seconds.
- The server shall re-send messages not received by the client.
- Events exceeding the time limits should still be shown to the user.
- The system should work in all popular web browsers, Internet Explorer 9 or newer.

As mentioned in section 2.1.1, classical real-time on the web is impossible since the underlying technology is best effort. The usual definition of real-time on the web is when the information comes so fast that the delay is not noticeable to the user. There are several theories for sending real-time video over the Internet, see section 2.2.1, for the firm real-time systems. This classification cannot be used in the dashboard since information loss is not acceptable and data that is delayed should still be displayed. Thus, the classification of the dashboard is soft. Furthermore, these theories are not applicable to the dashboard as it uses HTTP, which in turn uses TCP as transport protocol (Fielding et al. 1999).

In this study, there are no temporal validity intervals as described by Xiong et al. (2002). Deadlines are thus not imposed by the state of the data, as in many cases of traditional real-time, but rather derived from user experience aspects.

The time it takes from that an event is created until it is displayed on the dashboard needs to be measured, to know if the system fulfills the real-time requirements. No

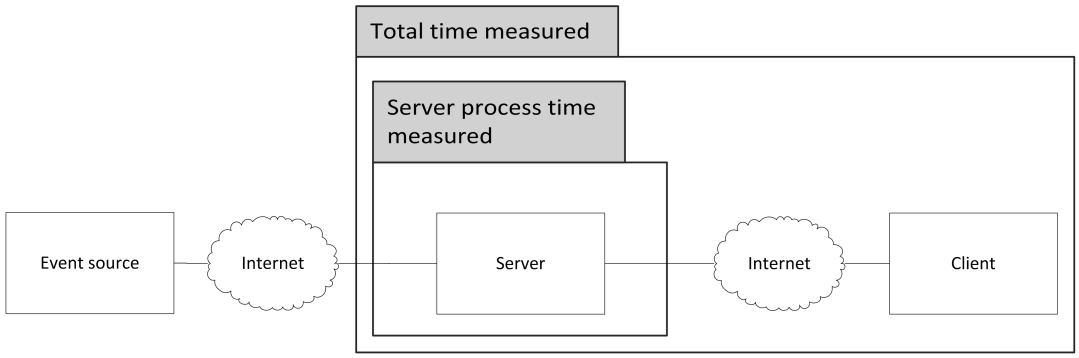

Figure 3.3: The parts of the event flow measured.

measures to control the systems that generate the events and what information they want to send to the dashboard was implemented. Thus it was decided that the time to focus on measuring and minimizing is the time from an event enter the dashboard system until it is displayed. Two metrics were used to know what parts of the dashboard system that needed to be improved: one that counts the total time and one that measures the time it takes for the server to process the information. As can be seen in figure 3.3, the different parts of the client and the server were not distinguished since only the total time and when it differs were of interest. Important in this study was whether it is the client or the server that is the problem.

3.3.2 Suggestion and Development

Based on the initial requirements, an initial design of the system's architecture was constructed. This architecture then served as a basis for a prototype system. The prototype was evaluated to determine how well it performs against the initial quality requirements. A demonstration of the prototype was made to the stakeholders to get feedback and ideas for the implementation of the proof-of-concept system. The prototype was then extended and used as the core in the proof-of-concept system.

Development of the proof-of-concept system was conducted on a weekly basis with reviews with customers ending every week. At these occasions, the progress of the week was demonstrated and the following week was planned. This included re-prioritizing the requirements for the system and setting goals for what were expected to be completed the following week.

3.3.3 Evaluation

To answer the research questions the evaluation was split into to two parts: a qualitative and a quantitative study.

Qualitative study

Interviews were conducted with employees at Surikat after they used the dashboard in order to answer research question 3. The user tests are in the context of aid for software development processes as Surikat is a software engineering company. Three employees at Surikat have been included in this process. Following is a presentation of the employees' roles and experience in the industry:

- Project manager, software delivery manager for 1.5 years and with 6 years of experience in the industry as a software developer.
- Project manager, system delivery manager for 3 years and has worked as a software developer for 6 years.
- Lead developer with 15 years of experience.

Both authors held all interviews, where one had the role of the interviewer and the other of the transcriber. The questions posed during the interview can be found in appendix A. Each interview took 15-30 minutes.

Test period
During a period of two weeks, the system was hosted on a development server at Surikat enabling employees to test the system. The test period started with a presentation of the dashboard at a monthly meeting. Here, the basic functionality of the user interface and the system capabilities were explained. An API documentation for the data insertion interface was also mailed to requesting participants after the meeting.

In addition to the possibility to access the dashboard from workstations, a Raspberry PI[1] displayed the dashboard on a large screen in the area most developers work in. Displayed here were a mix of different graphs showing data from the sources described in section 4.1.6.

Quantitative study

A quantitative study was performed on the dashboard after the development phase. The system was stress-tested with a varying number of simultaneous clients and amounts of data to give an indication of how the system scales for large user environments.

Metric collection
Measuring the time from the moment an event enters the system until the client receives it presents some difficulties. Simply checking the time on the server when sending and the time of reception in the client is not guaranteed to give accurate data since the clocks in the server and the client might not be synchronized. This was solved by syncing the server clock to an NTP, Network time protocol, server and then let the client sync its clock to the dashboard server, so that both clocks are in sync.

[1] http://www.raspberrypi.org/

In addition to measuring the time from server to client, the round-trip time, RTT, is also measured. The RTT is measured in the server and acts as some indication of measurement problems in the client.

Test setup

The server used in the quantitative study had an Intel core 2 duo E8400 CPU, 8GB of DDR3 RAM, 100Mbps Internet connection and was running Ubuntu 12.10. The database is MySQL 5.5[2] and Java environment OpenJDK 7u21[3] with the servlet container Jetty 9.0.2[4]. The Java virtual machine allowed a maximum of 2GB of RAM.

In addition to the measurements from the built in metric system, the study also included measurements of the server resource usage. The parameters measured during the test were the average CPU usage in percentage per core, average RAM usage in bytes and average network traffic in bits per second. These were collected using a set of utilities installed on the server.

The test was executed with 1, 5, 10, 25, and 50 different clients connected to the system. Each test was run for one and a half minute and between each test, the database tables were truncated. The time of each test was chosen based on it being long enough to have a fairly constant flow of incoming data while keeping the test time down to allow for more test runs. The clients were all running Windows 7 as the operating system and 50% were using Internet Explorer 9 as web browser the rest used Chrome 26; all were connected to Chalmers network. Data were sent into the system at 1, 10, 20, and 80 messages/second, by posting events to the system with a script. The script was run locally on the server so that the data insertion should not affect the bandwidth to the server. The script generates new messages at a constant rate, which might not reflect real-life usage patterns. It does however show how the system performs during high load periods which is likely to represent worst case usage.

Two types of subscriptions were used in the test: one showing time series data and the other one displaying the data summarized and grouped by name. This was done to test the different types of event handled by the system. How subscriptions work is described in section 4.1.5. The two subscriptions were not loaded in the same test so the test was executed twice. For the configurations used in the test see appendix D.

Analysis

After the stress test, the data were analyzed to determine if the system fulfilled the real-time requirements.

The system load was compared to the number of messages sent to the system with the different numbers of clients connected; the tests were performed for all types of subscriptions. This was done to give an indication of how the system scaled and what the limits for the maximum number of clients and messages per second are.

[2]http://www.mysql.com

[3]http://openjdk.java.net/

[4]http://www.eclipse.org/jetty/documentation/9.0.2.v20130417/

To determine if there is a difference between different browsers, the time measured from the different browser were compared in a diagram and a Welch's t-test was preformed on the data. Welch's t-test was used since it is a version of Student's t-test that works where the variance of the two populations is not equal (Welch 1947). A statistical significance of 0.05, as is customary, was used in the test. The null hypothesis is that the browser used should not affect the time for updates to pass through the system.

4 Results

In this chapter, the results from the studies are presented. Firstly, the architecture implemented in the proof-of-concept system is described. Secondly, the data gathered from the performance tests are presented. Lastly is a summary of the interviews conducted with employees at Surikat.

4.1 Architecture of the dashboard

One major architectural decision was to base the implementation solely on open source frameworks and third party software. This decision is based on that it is hard to motivate the investment in propriety third-party frameworks and technologies when working with emerging technologies with an uncertain future.

When working with open source components, it is important to understand the license agreement. If one has the intention to commercialize the product, one must make sure that the software is not bound by the licenses of third-party components in such a way that prohibits this.

4.1.1 Architectural drawing

The architecture is designed to be event-driven where data generators input data into the system at one end and events are generated to the clients that subscribe to that type of event data.

The flow of information in the system is similar to that described by Michelson (2006). The architecture fits well for the system, as most operations in the system are in some way the result of new events with new data entering the system. In figure 4.1, the major components of the system are shown. The components in the box labeled 'GWTClient' are all part of the client and the rest of the components are part of the server. The server side code is implemented in Java; the client is implemented using Google Web Toolkit, GWT[1], as Surikat had previous experience with the framework.

The system is designed to be easily extended with more functionality. This is achieved in mainly three areas. Firstly, it is possible to replace most components of the system with a different implementation. This is possible due to use of the dependency injection pattern (Fowler 2004). Spring framework is used for configuration of the dependency injection on the server side; on the client side, dependency injection from GWT is used.

[1] https://developers.google.com/web-toolkit/

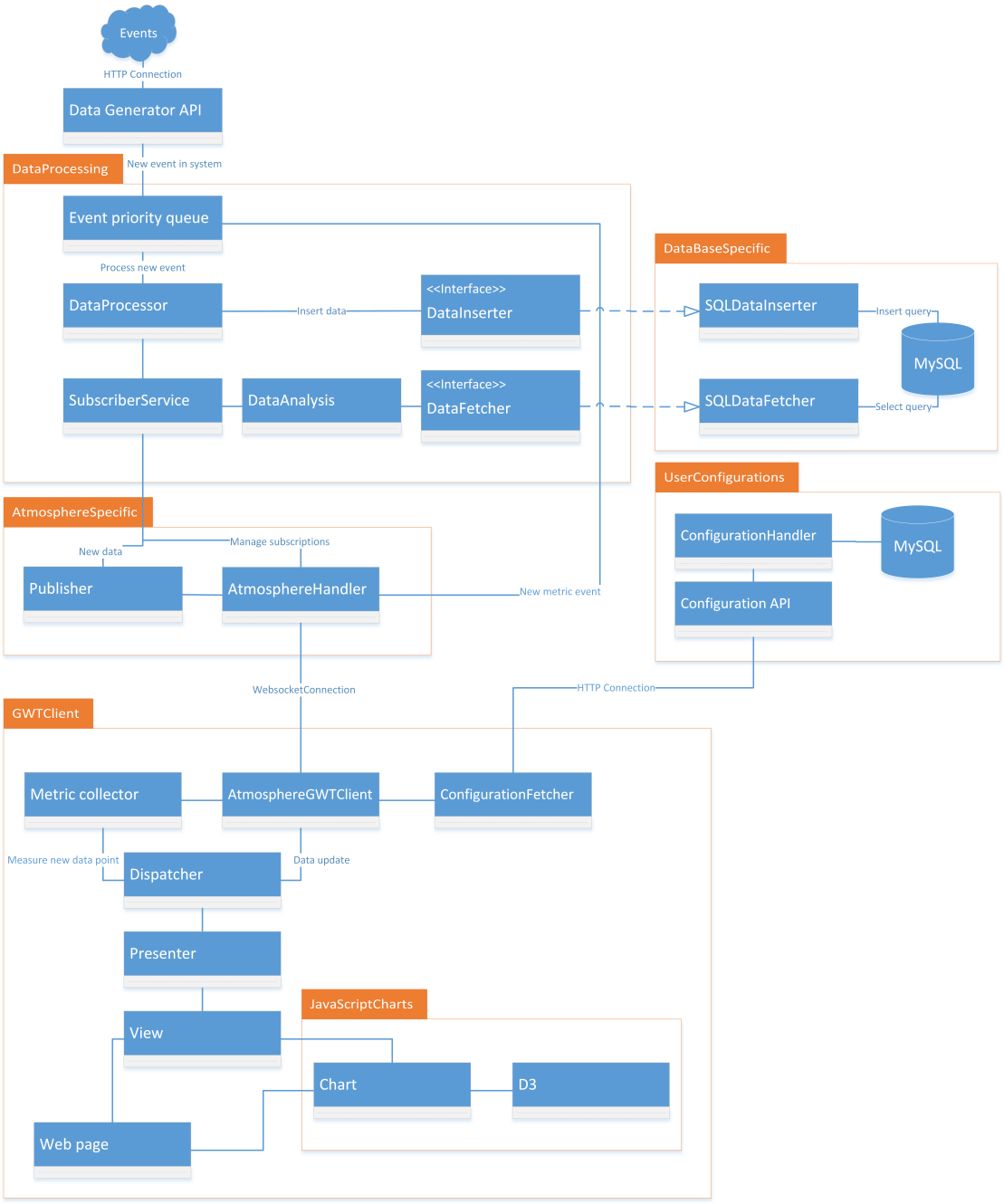

Figure 4.1: Architecture of the proof-of-concept system

Secondly, it is possible to add new data sources during runtime. How this is achieved is described in more detail in section 4.1.6. Lastly, all graphs are implemented in JavaScript and are looked up based on their name. To add a new graph, one simply includes the source file of the graph in the HTML-page, adds the line looking up the name of the new chart in a chart factory and it is available for the application without requiring the entire system to be rebuilt.

The client-side code is the critical part when attempting to achieve compatibility with different types of devices. The use of GWT, which is compiled to regular JavaScript (Google 2012), assured that most web browsers would be able to use the basic functionality of the application (Deveria 2013*b*). Two additional techniques are used to provide full functionality. Firstly, WebSocket is used to provide the communication between the server and the client. WebSocket is supported by most of the newer browsers on all devices (Deveria 2013*a*). Secondly, SVG is used to display the visualizations. SVG is also supported by most of the newer browsers (Deveria 2013*c*).

4.1.2 Communications

WebSocket is used as the transport protocol for Internet communications in this thesis. When using WebSocket, it is possible to use a sub-protocol for defining how messages are sent across the connection. For the implementation described in this thesis, it was decided not to use a special sub-protocol. Instead, JSON formatted strings are sent using the Java framework atmosphere[2]. The selection process for the WebSocket framework is described in appendix C. This is the simplest approach and gives the most flexibility with regard to client implementation. The implementation might require more work in cases where there already are good frameworks for a sub-protocol but it is simpler to implement in case no framework is available.

Communications were implemented according to the publisher-subscriber pattern where the node transmitting data, the publisher, has no knowledge about the receiver, the subscriber. The connection of subscribers to publishers is handled by the middleware, which in the case of this thesis is the framework Atmosphere (Eugster et al. 2003).

4.1.3 Real-time aspects

The efforts taken to fulfill the real-time requirements stated earlier in this thesis are divided into three separate areas. To begin with, the different data sources can be defined with different priorities. A data source with priority 1 has the highest priority in the system and is placed earlier in the execution queue. If multiple data points have the same priority, the first to enter the system is processed first.

Secondly, a system for post-mortem analysis of the system's performance is built in. This makes it possible to give a statistical estimation of the time it will take to process and send the next data point based on the current trend. The metric system is basically implemented as other data generators, but the data is inserted by sending it through

[2]http://github.com/Atmosphere/atmosphere

the WebSocket connection, as can be seen in figure 4.1, instead of using the REST API. How the measurement system works is described in greater detail in section 3.3.3.

Finally, the database is only involved in updates that aggregate data. This allows data points for time series subscriptions to pass through the system with little processing.

4.1.4 Database

As can be seen in figure 4.1, the system uses two databases. One database, the one in the box labeled 'UserConfigurations', is used to store the user configurations and metadata for the widgets visible on the clients. The second database is used to store the data inserted by the data generators.

The selected database is MySQL, which has less functionality in the field of data analytics than other alternatives discussed in section 2.2.4, but is easier to integrate into the rest of the system since it is well supported by Spring framework. The effects of the database choice are that some SQL and database specific features had to be developed. These features are: conversion from JSON based subscriptions to SQL statements, post-processing and filtering of data.

4.1.5 Queries and subscriptions

The developed dashboard concept revolves around the idea of subscriptions. A subscription refers to a persistent query on the dataset with aggregations, filters and groupings. The format for queries designed in this thesis was influenced by the query format used by Druid (Yang et al. 2013).

Subscriptions are divided into two categories, "group by" and "time series", to fulfill different needs. These subscription types map against the different processing styles described by Michelson (2006). Time series subscriptions are based on the concept stream event processing where new data points are forwarded to clients that subscribes to that type of data. Group by subscriptions are related to complex event processing and often require the server to recalculate aggregations to fit the new data into the context of the subscription.

The difference between the format of time series and group by subscriptions is small. Group by subscriptions are the most complicated as they have more properties. An example of a group by subscription is shown in figure 4.2. This subscription gets the average time it took to send the last five data points filtered to only include devices sharing the same platform as a Raspberry PI. There are a few particularly interesting properties of this subscription. Firstly, 'clientToken' is a property that is used when registering the subscription and assigning a publication path. Secondly, the 'data' object which contains what data source to use and properties for selecting the fields from that source. Finally, we have the 'postAggregations' property. This specifies computations to perform in the 'DataAnalysis' component shown in figure 4.1. In this case, an average is computed from the field 'timeDiff'.

```
{
  "queryType":"GROUPBY",
  "clientToken":"metricAvg",
  "data":{
    "metric":{
      "aggregations":[
        {
          "type":"value",
          "fieldName":"timeDiff"
        }
      ],
      "aggregationFilter":{
        "type":"selector",
        "dimension":"platform",
        "operand":"=",
        "value":"Linux armv6l"
      }
    }
  },
  "orderBy":{
    "field":"id",
    "order":"desc"
  },
  "maxReturn":5,
  "postAggregations":[
    {
      "type":"statistics",
      "name":"timeDiffAvg",
      "fn":"avg",
      "fields":[
        {
          "type":"fieldAccess",
          "name":"timeDiff",
          "datasource":"metric"
        }
      ]
    }
  ]
}
```

Figure 4.2: Group by subscription

A time series query would look similar to that of figure 4.2 but with fewer properties and the property 'queryType' set to 'TIMESERIES'.

The separation of subscription types is also beneficial for performance. By using group by subscriptions and doing all aggregations on the server the client has lighter work to perform and the amount of data sent between the server and client can be minimized. This is important for meeting the time constraints on all types of clients. In addition, performing calculations on the server is anticipated to reduce the total amount of computation, as multiple clients with identical subscriptions only require the calculations to be performed once.

4.1.6 Data generation

In effort to decouple the sensors collecting data from the system, insertions are performed through a web service running a REST interface. The basis for this decision is that Surikat indicated that most systems that would feed data into the dashboard would be web-based, making the HTTP protocol the natural choice. The decision to use REST rather than SOAP was due to the simplicity of REST.

One could argue that there are more suitable solutions for data generators that are not web-based, such as various hardware sensors. But as more and more devices are connected to the Internet (Atzori et al. 2010), a REST API is compatible with more than just web-based data generators.

Implementation of data generators

While it was not the focus of the thesis to develop data generators to hook into existing systems, a few simple examples were developed for testing purposes. Most useful is a post-commit hook created for the version control software Git[3]. The generator inserts the time, branch, author and number of changes for a commit into the system after it is made. Other implemented data generators were a random data generator and an application that inserts what keys a user presses on the keyboard. The last example was implemented by one of the interview subjects as part of the user testing.

Inserting data

When a new data generator is created, it needs to be connected to the dashboard's data insertion API. The first step is to create a database table for the new data source. This is done by making an HTTP Post request with a JSON specifying the properties of the data source. An example of such a message, used to create the table for the Git data generator, is shown in figure 4.3. Defined here are some properties for the table and what columns the table should have. All properties of the data source have an identifier, which must be unique in its scope. That means it must be unique for each source and for each column within a source. The name property is the display name in the user interface. A data source can define a priority. How priorities work is described in section 4.1.3. If no priority is defined, a default value of 100 will be used. All columns also have a data type defining what the system should expect in new data points.

[3] http://git-scm.com/

```
{
  "Identifier":"git",
  "name":"Git",
  "priority":1,
  "columns":
  [
    {
      "identifier":"author",
      "datatype":"string",
      "name":"Author name"
    },
    {
      "identifier":"date",
      "name":"Commit date",
      "datatype":"long"
    },
    {
      "identifier":"changes",
      "name":"Number of changes",
      "datatype":"long"
    },
    {
      "identifier":"branch",
      "name":"Branch name",
      "datatype":"string"
    }
  ]
}
```

Figure 4.3: JSON payload for creating Git data source

When the database table is created, it is possible to insert new data points for that data source. These are also inserted by performing an HTTP Post request with a JSON payload. In figure 4.4 is an example of how a new data point is inserted into the table of the data source from the example in figure 4.3. The data point contains a source, which is the unique identifier for the data source the point belongs to, and a data object. The data object has the identifier of all columns in the data source as keys and a value of the corresponding data type defined when creating the source. All columns are optional and can be ignored if no data exists.

```
{
  "source":"git",
  "data":{
    "author":"Martin Hesslund",
    "date":1300020202,
    "changes":100,
    "branch":"master"
  }
}
```

Figure 4.4: JSON payload for inserting data to Git data source

4.2 Measuring latency

In this section, data from performance measurements are presented.

4.2.1 Server load

Memory usage during the test was around 1.3GB for Java and 55MB for MySQL independent of the amount of data sent to the system and the number of clients connected. This can be explained by that there is no cache function implemented in the code and the little extra memory it took to handle more connections is not noticeable.

The CPU usage did increase as the number of clients and the data flow rose. It is possible to see in figure 4.5 that the CPU usage of Java increases rather linearly to the number of messages processed. This is due to each message using roughly the same amount of processing power. MySQL's CPU usage did not increase that much when running the time series subscription. This can be explained by the database only performing insertions of data with this type of subscription. In the group by test, the load on the database is higher since it not only needs to insert the data but also summarize the entire table on each new message.

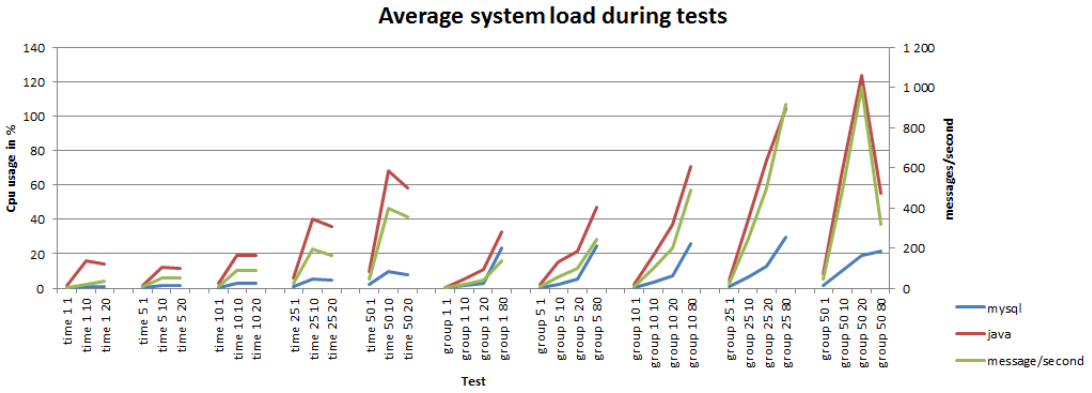

Figure 4.5: CPU usage on the test server during each test. The test name is according to the following pattern: type of test, number of clients, message/second

One thing that needs to be mentioned is that the total number of messages is higher than the amount sent to the system by the script; the real number of messages received per second can be calculated by the following equation:

$$numberofevents/second + clients * numberofevents/second = numberofmessages/second$$

The extra messages are sent by the measurement system.

4.2.2 Latency

Due to problems when trying to sync Internet Explorer's local clock, time measurements from those clients during the tests cannot be used. To get latency information comparable between different browsers, the round trip time is used in the data analysis.

During the stress test of the system, the overall average round trip time, RTT, for the messages collected is 5066ms. The total number of metric points collected during the tests are 510801, which is on average 162 points per second. The average RTT is higher than the requirement for the system which is to not be above 2000ms. For the tests with a lower number of clients and less messages per second, 52.7% has an average RTT of 143ms, which met the goal time of 2000ms. The requirement that the max RTT should not exceed 10000ms is not met for either selection of the data.

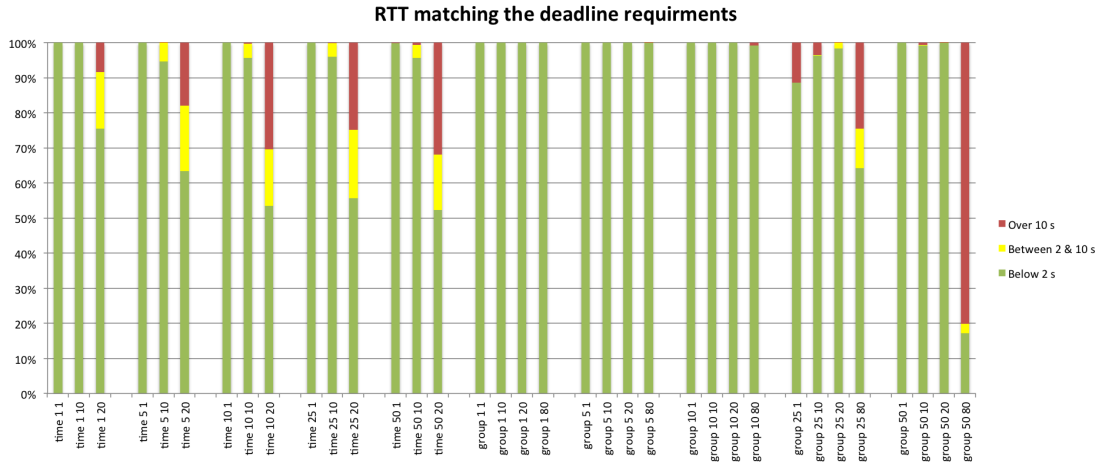

Figure 4.6: Round trip times, in procentage, that meet the real-time requirments

As can be seen in figure 4.6, most tests meet the deadline from the real-time requirements. In total, 87.2% of the messages are displayed before 2000ms and 91.3% are displayed before 10000ms after they enter the server. The average RTT for the messages over 10000ms is 54320ms.

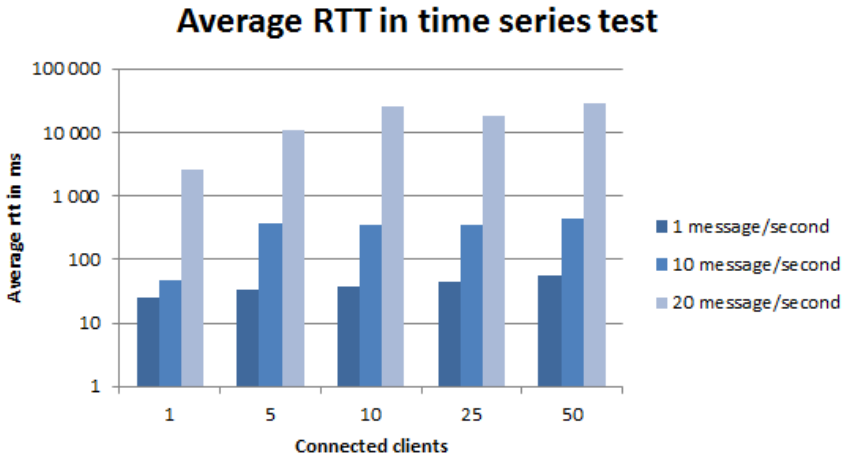

Figure 4.7: Round trip time in average during time series test, the figure use a logarithmic scale with base 10

The test with the time series subscription showed that the system had no problem severing the clients with new updates, see figure 4.10. However, as can be seen in figure 4.7 and figure 4.9, the average RTT rose as the number of clients and messages increased. This happens for both web browsers and can be explained by the rendering of the chart in the client. The JavaScript used to display the chart have a problem with the time series graph when the number of messages per second is higher than one. At that frequency, the array that is used to store the data do not have time to remove the old data until a new data point is revived which cause a memory leak, which crashed the client. As a result of the crash, less metric data is sent to the server, which is visible in figure 4.10. Because the clients crashed when sending 20 messages/second, the test with 80 messages per second was not executed with the time series subscription.

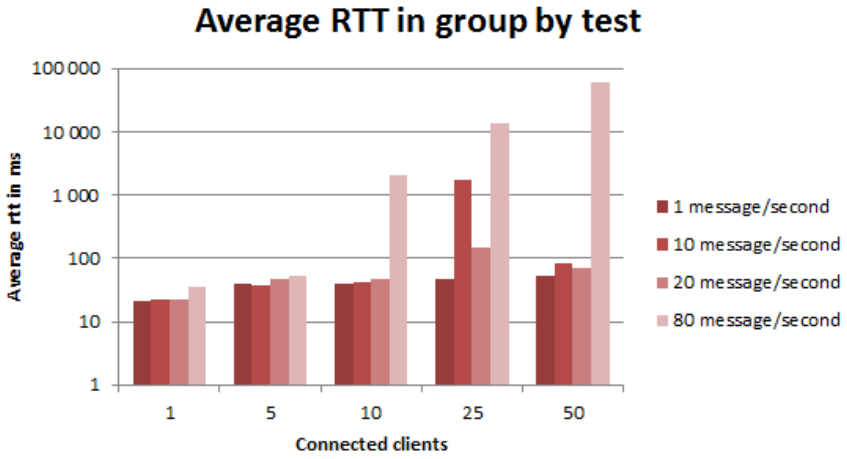

Figure 4.8: Round trip time in average during group by test, the figure use a logarithmic scale with base 10

The average RTT measured during the group by tests is 5490ms, see figure 4.8 for the RTT in each group by test. Time series test have the average RTT of 3646ms.

The Welch's t-test gave the p-value $2.2e^{-16}$, which shows, with a statistical significance of 95%, that the null hypothesis can be rejected. The alternative hypothesis, that the choice of browser affects the RTT, is therefore valid. By comparing the different web browser types, it is, in figure 4.9, possible to see that Internet Explorer 9 has a higher RTT than Chrome 26 especially when the number of messages increases. The average RTT for Chrome is 1640ms and for Internet Explorer is it 17285ms and when looking at the time it take for the message to be received in the client the average for Chrome is 508ms and the value for Internet Explorer is completely wrong, -407717ms, since the clients have failed to sync the clock.

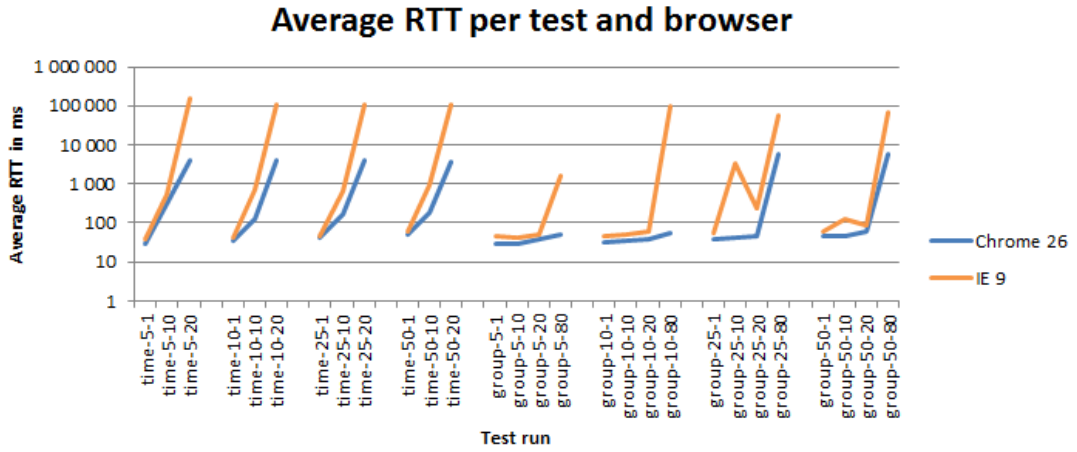

Figure 4.9: Round trip time per web browser, the figure use a logarithmic scale with base 10

In the group by with 10 messages/second and 25 clients connected, the Internet Explorer clients have a problem showing the messages in time. As can be seen in figure 4.10, the server-side system did not have any problem and with the amount of data. It is possible to see that it was one single Internet Explorer client that had problems by looking at the complete data set for that test.

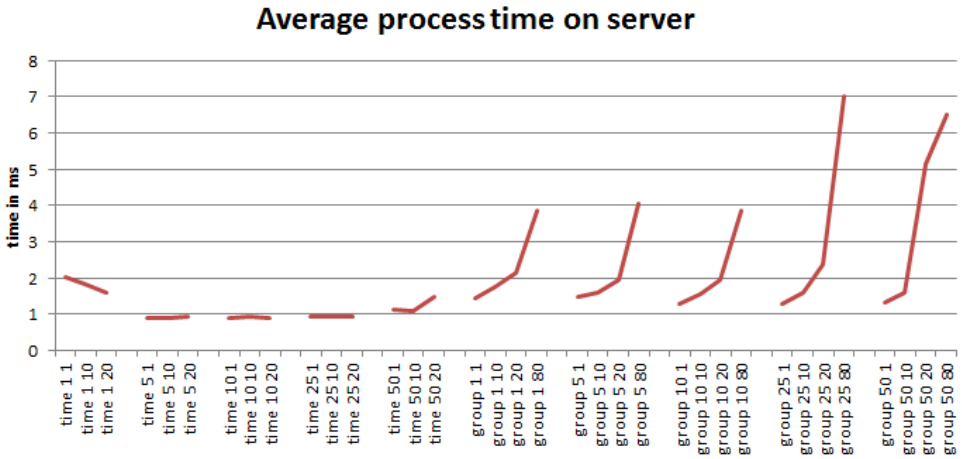

Figure 4.10: Average process time of each message on the server

Processing the messages on the server is generally not a problem during the tests, see figure 4.10. However during the group by tests with 25 and 50 clients and 80 messages per second, the average processing time started to increase and the maximum processing time increased by 250% compared to the test with 20 messages/second. This indicates

that the server is approaching its maximum capacity. Furthermore, it is possible to see that there are some inaccuracies in the measurements. The group by test with 80 messages per second and 25 simultaneous clients had a higher average processing time than the test with 50 clients. This could be related to the disconnection of clients discussed further in section 5.1.

4.3 Benefits of real-time dashboards

This section presents the results of the qualitative study conducted in order to gain perspective on the perceived advantages of having instant access to information. This study was, as described in section 3.3.3, performed by letting users work with the system and answering questions during interviews.

4.3.1 Interviews

This section summarizes the interviews that followed the user tests of the proof-of-concept system. This section is divided into subsections based on topics in the interview questions. The full list of questions is found in appendix A.

Information usage

When asked what systems the interviewees regularly extract information or reports from the answers are relatively similar. The three most used systems were the build and continuous integration software, the bug tracker and the time report system. These systems are used on a daily basis by all interviewees and are business critical as they provide information required for the billing of customers.

There was also a desire to combine data from different sources in a simple manner. This was described as too difficult without tool support. An existing solution explained was an integration database that is used to combine data from two different systems. This solution was a bit complicated and not flexible enough to be extended with more functionality. One example of visualization not possible with this solution is to get all unfinished tasks for a project and the number of hours spent on each.

Another thing one project manager mentioned was that it is sometimes necessary to visit several different systems to get access to all information needed for one task. This takes significant time and is something that should be possible to perform more efficiently.

Some of the reports regularly used by the interviewees contain more advanced visualization than those available in the proof-of-concept. This implies the need for simplicity in extending the system with additional visuals as new needs emerge.

Usefulness of real-time updates

According to interviewees, having real-time updates of developers' entries in time reporting systems and bug trackers is a time saver for project managers. This allows for

tracking of progress on a finer level than possible with periodical reports. It was also mentioned that fresher information gives better support for decision making and faster access to information results in better decisions.

It was also positive that while the updates were instantaneous, they were not as demanding and disturbing as notifications via mail. Mail updates had a tendency to clutter the inbox of the user and were often thrown away before they were read.

Real-time updates on an information radiator were described as motivating. Laggards would be encouraged to enter information, such as time reports, directly after finishing tasks rather than waiting to the end of the week. It was hypothesized that this would improve the accuracy of the time reports. Project managers would also save time, as they would not have to spend time asking people if they had filled their time report and let developers work undisturbed until they were ready to input their info.

Although the attitude was generally positive, real-time updates were not perceived as beneficial in all cases. One example is that some reports are based on data from the latest quarter and here it makes less sense to have the data from the beginning of the quarter until the current date.

Tool integration

Two of the interviewees had tried to add a data generator to the system. Their general opinion was that it was fairly simple to work with the API but requested more options for inserting data. The API seemed powerful enough but there was an uncertainty if it would be flexible enough; a concern that is hard to address until more advanced data sources are integrated.

According to one subject, the fact that the API only accepts one data point with each event might put unnecessarily high load on the system generating data if the frequency is high but the need for continuous updates is not. The suggestion was to allow the generator to collect events under a time span and send them collectively as one event to the dashboard. It was also suggested making it possible to sidestep the event-driven nature of the API and let the dashboard poll the generator for new data at intervals.

Another related note was that sometimes the problem is not in what way the data is fetched or inserted into the system, but rather the format of the data. Systems where people input free form information needs either strict routines for how the data shall be formatted or very intelligent semantic parsing if useful visualizations are to be produced from it. One example was absence from the office, which is not always reported in the same way.

User experience

Only one of the interviewees had tried using the system on a mobile device, using Android. He tried both the standard Android browser and Chrome for Android where Chrome gave a superior user experience.

Most of the popular desktop browsers were represented among the interview subjects. The exception being Opera and Safari which none of the interview subjects used.

All of the interviewees stated that the user interface needs more polish in order for the system to be usable in their actual workflow. Another point discussed regarding the user interface was how to control the position of the widgets. The widgets in the proof-of-concept system were placed on the screen in a floating position. One interviewee would have preferred more control over the widget position, such as one would get from placing the widgets freely on a grid.

5 Discussion

In this section are comments on the results as well as discussion of the ethical implications the dashboard system could have.

5.1 Performance

As seen in the results, the system performs well with low load, but the RTT increases when the number of clients and messages grow. Why the RTT increased has different possible explanations for the two types of tests.

In the time series test, the JavaScript in the client is the big problem. It caused the client to crash due to a memory leak when handling the new messages and it needs to be improved to work when a high amount of messages per second is sent to one graph.

The group by test did not have the same problem with the JavaScript, even though the amount of messages per second were higher than for the time series test. This is because the information in the graph is replaced for every new message allowing JavaScript to garbage collect the old message. The server did on the other hand have a higher load during this test. The system setup reached its maximum amount of client, 50 clients connected and 80 messages/second, but the server load never reached 100%. One possible explanation for the problem is that the router used to hit its maximum number of concurrent connections and therefore had problems receiving the metric data. The router used in the tests has a maximum of 200 connections according to a test by the website SmallNetBuilder (Higgins 2009). The number of connections used during the test can be calculated as follows: 50 for the Chrome clients, one for each WebSocket connection and one used for time synchronization, 150 for Internet Explorer, 6 for each client to receive messages and send metrics (Lawrence 2011). This gives a total of 200 connections for the clients plus a few extra connections for system monitoring and various background processes.

While the server load never reached 100%, it started to increase rapidly, see section 4.2.2. The server used, see section 3.3.3, is a five year old desktop computer. Moore's law suggests that a modern server would have at least four times better computation power than the one used in the test. Thus the system would be able to handle a lot more messages and clients when running on a modern server.

In the results, it is shown that Chrome is faster than Internet Explorer, see figure 4.9. This can be explained by IE 9's use of long polling for transporting the messages. For each message received, the connection to the server is closed and a new one needs to be opened. Chrome 26 can send and receive messages over WebSocket so no new connection

needs to be opened and less overhead is sent with each message (Agarwal 2012). The performance of the client is likely to improve as the latest version of all the popular browsers all have support for WebSocket (Deveria 2013*a*). In addition, JavaScript is getting faster and faster with each generation of browsers.

Round trip time is used during the measurement to determine if the system achieves the goal of max 10 second for a message to be displayed in the client, however that does add extra latency on the measured time since the message has to comeback to the server. In section 4.2.2, is it mentioned that the time for a message to be displayed in the client is much lower than the RTT, but could not be used since Internet Explorer has problems with clock syncing.

5.2 Benefits and applications

During the interviews, project managers seemed more positive than developers to the need for real-time updates. This might be attributed to project managers having tasks more frequently depending on accessing and evaluating information, or noticeable shortcomings in the tools currently used.

When using information as support for making decisions, the more current the information the better. When one has access to the latest data, less guessing about the current situation or wait for the data to be collected are required. This makes it possible to use information visualizations where data collection was previously too slow, leading to support for more decisions. This aligns with the points that emerged during the interviews; decision making has to be quick and effective, which is not possible if one relies on information that takes a long time to collect.

Two interviewees stated that having real-time updates on a large screen visible for all developers was motivating. One example mentioned was filling time reports after every different task instead of estimating the time spent on each project at the end of the week. It is previously established that information radiators increase motivation in agile teams (Whitworth & Biddle 2007) and seeing the radiator update instantly might increase this motivation.

Not all information needs to be updated continuously. Some information the interview subjects work with is in reports from fixed time periods, such as quarters. While these types of reports are still necessary, continuous updates can be used to follow the progress for the current period and compare it on a fine level to previous results.

Mentioned during the interviews was that the unobtrusive nature of the dashboard is a good quality. This contradicts findings by Jakobsen et al. (2009) who state that a redesign of their system, WIPDash, would have included more noticeable alerts. This might be the result of different ways of working with information. WIPDash facilitates what Treude & Storey (2010) describes as low-level awareness where information such as what files are currently being worked on is displayed. The uses for the dashboard mentioned during the interviews were more related to high-level awareness. Another difference might be how the dashboard is used. If the dashboard is ever present in the background, notifications might be helpful in directing focus to the changes. But if the

dashboard is a place visited for a task to obtain certain information, notifications from it when no information is needed might be disturbing.

The desire for notifications can also be related to the frequency of updates. If events happen seldom, it might be helpful to be alerted of the change whereas in cases where events are frequent, it might disrupt the work on other tasks.

5.3 Design trade-offs

The system is designed, as mentioned in section 4.1.1, with the focus of being easy to extend. This required some trade-offs regarding optimizing the system for real-time processing of messages. This is since the system does not know what information is available for the user and what the user want to analyze. To compensate for this, the events with the highest priority are processed first and events that do not need database aggregations are passed through the system with little processing, as mentioned in section 4.1.3. The rational for prioritizing flexibility over real-time properties is that the system would have to be very specialized for a single organization if this flexibility was not present.

Another trade-off is the event handling. Systems like Hackystat, has a buffered event middleware which makes it possible to collect information even if the system is not connected to the server (Johnson 2007). This limits the system in the area of real-time analysis. The dashboard system requires data sources to send the events as soon as they are generated to achieve real-time performance. To put this responsibility on the data generators are necessary to achieve a solution where the system does not need to poll the generators for new data all the time. For information that does not need to be real-time, the data source can implement its own cache functionality to be able to store a certain amount of events until it sends them to the dashboard server.

Another thing to keep in mind when adopting systems like the dashboard is compatibility with existing tools. As pointed out by Johnson et al. (2005): telemetry systems require the possibility to extend the tools used with sensors. If extension support is not present, it might be possible to create a script that extracts the information from the application and inserts it into the dashboard. For this to work efficiently, the API would have to be extended to support batch insertions that it, as mentioned in section 4.3.1, currently does not.

On the client, the JavaScript used to render the charts is flexible, thus making it possible to easily create new charts. The user can also specify what information that should be shown in the chart. This flexibility makes it harder to know if the system fulfills the real-time requirement. For example, as presented in section 4.2.2, the charts did not work as well as expected with high amounts of time series data. However, this trade-off is necessary as different users and teams have different visualization needs as Jakobsen et al. (2009) discovered in their study of WIPDash.

The dashboard works across all devices tested and gives continuous updates and using web technologies for this type of application seems very feasible. While the performance of mobile devices were not compared to that of desktops, it stands to reason that due to

the fact that wireless connections are less stable, the performance would be lower.

5.4 Ethical implications

This section discusses some of the different ethical implications of this thesis.

Usage of information

When dealing with information visualization systems, the ethical implications are largely dependent on the type of information displayed. In the case of software development monitoring, the information is often related to the development work and some metrics can thus be used to evaluate the performance of employees. It can be considered unethical to have such large insight into individual workers' day-to-day performance and care should be taken when using this type of information. This is an observation the creators of Hackystat have made as well (Johnson 2007).

Correctness of data

When working with data, there is always the possibility of errors. This could have consequences if vital decisions are based on the information. While it could be argued that whoever uses the information bear the responsibility of assessing its correctness, the tools shall provide as much aid as possible to the process.

Solicitation bias

As this thesis was conducted in collaboration with a company, there is always a risk that the interests of the company have affected the outcome of the study. To avoid this potential bias, a few measures were taken.

Firstly, efforts to align the goals of the study and Surikat were made such as creating a plan at the beginning of the thesis and agreeing on the course of action.

Secondly, while Surikat have provided continuous feedback with regard to the features of the proof-of-concept system, the work on this have been conducted independently.

Finally, an interest to create an academic study was shared by all parties.

5.5 Threats to validity

We recognize that there are several threats to the validity of this thesis. Following are the major threats identified:

- The clients used in the performance test were all running on the same type of hardware connected to the same network. This was due to the use of a classroom as a test lab. Though similar clients might not represent actual use of the system, it allows for comparisons between different web browsers and reduces the number of unforeseen dependent variables.

- Only one data source, visualized in one graph, was used during the stress test. This does not simulate the daily use of the system. However, this was used for easier comparison between the different event types.
- The tests were only executed for one and a half minute. Running longer tests might have revealed performance problems that do not arise until the system has been online for longer periods of time. As all tests ran for an equally long time, comparisons between them should be accurate.
- The number of interview subjects was only three. However, as each interviewee had several roles, most roles in software projects were represented. Furthermore, the total number of employees at Surikat limited the number of potential interview subjects.

6 Conclusion

This thesis examined the benefits of real-time updates in information dashboards by implementing a proof-of-concept system and conducting performance measurements and interviews with employees at Surikat. During the study, it was found that access to real-time updates of information are helpful to software engineers, and project managers in particular.

The interviews revealed that real-time information in dashboards are beneficial in several ways. Firstly, the fast updates allows project managers to base more decisions on data which was previously not available. Secondly, project managers save time by always being able to get an up-to-date overview of data from different systems, such as time reports or bug trackers, without spending lots of time asking all developers about their progress. This also lets the developers focus on their work. Finally, when the dashboard is shown on an information radiator, the instant updates are motivating as seeing the data change gives incentive to finish more tasks or update time logs directly after a task is completed.

The interviews revealed that not all information needs real-time updates and that the way data are analyzed sometimes requires data in fixed time periods. One major time-saver is instead the automatic collection of all data from different systems into one system so no manual labor is required when combining the different sources of information.

While the web is not designed for true real-time communications, it is possible use WebSocket for soft real-time communication without predictable execution times when using the latest web browsers. WebSocket is also gaining support on mobile devices making web applications suitable for uses when the targeted devices are widespread.

In the performance tests conducted in this study, it is possible to see the large differences between new and older web browsers. Google Chrome 26 from 2013 performed significantly better than Internet Explorer 9 from 2011; this was likely due to the inclusion of WebSocket in Chrome. It stands to reason that the performance achieved in the fastest web browsers will spread to all web-connected platforms.

The duration of this study was rather short and further investigation in the area is necessary. Following are some suggestions for future work:

- Further study of the dashboard's performance during actual use. This would give more accurate data regarding usage patterns and better insight into what parts of the system are slow and unpredictable. Here it would also be desirable to conduct more tests with mobile devices to find how the performance differs between different platforms.

- While the underlying technology works similarly on desktops and mobile devices, the usage scenarios might be vastly different. Thus it is important to understand how mobile clients are, or could be, used for consuming project information. This would give better insight into if specialized interfaces are required for these devices.
- Not covered in this study is how real-time information can be integrated into development processes. In particular, it is necessary to develop guidelines for how it should be determined what information each organization benefits from having real-time access to.

This study was conducted in the context of software engineering projects but the benefits of real-time dashboards are likely transferable to other business areas where dependence on periodical reports is the current practice.

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A Interview questions

- What is your position?
  - How many years have you worked in that position?
  - How many years have you worked in the industry?
- Could you describe what type of information you regularly use in your work?
  - How often do you work with this information?
  - How important is the analysis of this information for your work?
- Do you today have information in periodical reports you would like to have instant access to?
  - If yes, what type of data?
- How long time do you think is acceptable to wait from the information is created until it is visible on your screen?
  - Is the threshold for acceptable time the same for all information you use?
- Do you today have information in different reports/systems that you would like to analyze/visualize in the same graph/dashboard?
- Do you perceive the dashboard as beneficial to your work?
  - What functionality in the system have you tried?
  - Describe what functionality you found most valuable.
  - Is there any functionality you miss in the system?
  - Could you describe a scenario where this functionality would make your work easier?
- Which web browser(s) did you use to access the system?
  - If more than one, was the user experience similar on all browsers?
- Which type of device did you use to access the system? (Computer, Smartphone, Information display, etc.)?
  - If more than one, was the user experience satisfying on all devices?

- Have you tried adding new data sources?
- Have you created an add-on to another software tool that inserts data into the dashboard-system?
- Have you used any similar tools? If yes, which ones?
  - How does this system compare to those tools?
- Do you believe you have gained a stronger base to stand on when making decisions using this new system?
- Is there anything you would like to add?

B User stories

B.1 Functional

B.1.1 Control panel

ID: DF:Con-1	**User story:** As a user I want to be able to manage my dashboards	**Origin:** Product owner	**Dependency:**
Description: There should be a control panel where users can manage their dashboards and widgets. **Rationale:** Users shall be able manage their dashboards.			

ID: DF:Con2	**User story:** As a user I want to be able to create dashboards	**Origin:** Product owner	**Dependency:** DF-Con-1
Description: Users shall be able to create their own dashboards in the control panel. **Rationale:** Users shall be able to have different dashboard for different screens.			

ID: DF:Con-3	**User story:** As a user I want to be able to create widgets	**Origin:** Product owner	**Dependency:** DF-Con-2
Description: Users shall be able to create widgets to their dashboards in the control panel. **Rationale:** The dashboard needs to be customizable for all users.			

ID: DF:Con-4	**User story:** As a user I want to save widget template	**Origin:** Product owner	**Dependency:** DF-Con-3
Description: Users can save widgets they have created as a template and use with a different data source. **Rationale:** To save time for the user when creating a dashboard.			

ID: DF:Con-5	**User story:** As a user I want to be able to share widgets	**Origin:** Product owner	**Dependency:** DF-Con-4
Description: Users shall be able to share widgets with other users. **Rationale:** To help other users to create dashboards faster.			

ID: DF:Con-6	**User story:** As a user I want to be able to combine data sources in widgets	**Origin:** Product owner	**Dependency:**
Description: Users shall be able to combine data from several sources in a widget. **Rationale:** Helps users to see how different data sources affect each other and get a better understand of the current state of their project.			

ID: DF:Con-7	**User story:** As a user I want to be able to log in	**Origin:** Product owner	**Dependency:**
Description: Users needs to log in to be able to manage their dashboards. **Rationale:** Only users that should have access to the system should be able allowed to use it.			

B.1.2 Client

ID: DF:Cli-1	**User story:**	**Origin:** Product owner	**Dependency:**
Description: The client should load a configuration file from the server that describes what the dashboard interface contains. **Rationale:** The client should be customizable and only need to load a different configuration file to look different.			

B.1.3 Interface

ID: DF:Int-1	**User story:** As a user I want to interact with the dashboard	**Origin:** Product owner	**Dependency:**
Description: Users shall be able to drill down into the information in the widgets and the surrounding widgets should update to show information relevant to the selection. **Rationale:** The dashboard shall help users to visual data as they want.			

ID: DF:Int-2	**User story:** As a user I want to be able use the system on all my devices	**Origin:** Product owner	**Dependency:**
Description: The dashboard shall work on all devices that have a modern web browser. **Rationale:** The system shall work on all types of devices.			

ID: DF:Int-3	**User story:** As a user I want to visualize data on a map	**Origin:** Product owner	**Dependency:**
Description: The dashboard shall be able to visualize data on a map. **Rationale:** Maps are good to visualize position data.			

ID: DF:Int-4	**User story:** As a user I want to visualize data in a table	**Origin:** Product owner	**Dependency:**
Description: The dashboard shall be able to visualize data in table form. **Rationale:** Tables are good for combining data, e.g. project data from different sources.			

ID: DF:Int-5	**User story:** As a user I want to see a bar chart over the data	**Origin:** Product owner	**Dependency:**
Description: The dashboard shall be able to show bar charts with data. **Rationale:** Graphs is a good way to visualize data to the user.			

ID: DF:Int-6	**User story:** As a user I want to see a line chart over the data	**Origin:** Product owner	**Dependency:**
Description: The dashboard shall be able to show a line chart with data from the different sources. **Rationale:** Graphs is a good way to visualize data to the user.			

B.2 Quality

B.2.1 Interoperability

ID: DQ:IO-1	**User story:**	**Origin:** Product owner	**Dependency:**
Description: Communications between server and client must have support for the Java programming language. **Rationale:** The server side of the application will be written in Java.			

ID: DQ:IO-2	**User story:**	**Origin:** Product owner	**Dependency:**
Description: Communications between server and client must have libraries for JavaScript. **Rationale:** The client side application will be written in JavaScript.			

ID: DQ:IO-2	**User story:** Software licenses	**Origin:** Product owner	**Dependency:**
Description: The components in the system need to have software licenses that allow the customer to sell the system without having to publish the source code. **Rationale:** The system is going to be a part of a product.			

B.2.2 Performance

ID: DQ:Per-1	**User story:** Number of simultaneous clients	**Origin:** Product owner	**Dependency:**
Description: The system should handle at least 1000 simultaneous clients **Rationale:** There might be a large number of clients connected at the same time, all of whom shall receive continuous updates.			

ID: DQ:Per-2	**User story:**	**Origin:** Product owner	**Dependency:**
Description: The maximum duration from the time data enters the system until it is shown on any dashboard displaying that data-point is 10 seconds and should on average be at most 2 seconds. **Rationale:** Users should have up to date information on the dashboard at all times.			

ID: DQ:Per-3	**User story:**	**Origin:**	**Dependency:**
Description: Technologies that minimize overhead in communications shall be used whenever possible **Rationale:** Some clients might not have fast connections or the amount of data might be very high.			

B.2.3 Security

ID: DQ:Sec-1	**User story:**	**Origin:** Product owner	**Dependency:**
Description: User shall only see data from projects they have access to. **Rationale:** Data stored in the system can be sensitive and should only be accessed by users with appropriate permissions.			

ID: DQ:Sec-2	**User story:**	**Origin:** Product owner	**Dependency:**
Description: SSL should be used on all communication between the clients and server **Rationale:** Some data sent might be sensitive and should not be sent over the Internet unencrypted.			

B.2.4 Usability

ID: DQ:Usa-1	**User story:**	**Origin:** Product owner	**Dependency:**
Description: The Dashboard should work in all popular web browsers, Internet Explorer 9 or newer **Rationale:** The system is going to be used by different users on different computers.			

ID: DQ:Usa-2	**User story:**	**Origin:** Product owner	**Dependency:**
Description: The interface should feel responsive to the end user. **Rationale:** Users do not like systems that are slow and do not responds to their actions			

ID: DQ:Usa-3	**User story:**	**Origin:** Product owner	**Dependency:**
Description: The system shall be able to send data to clients of any type. **Rationale:** It should be possible to extend the system to other clients then web browsers.			

ID: DQ:Usa-4	**User story:**	**Origin:** Product owner	**Dependency:**
Description: A user with computer usage experience should be able to create basic widgets **Rationale:** The system should be easy to understand and use.			

B.2.5 Reliability

ID: DQ:Rel-1	**User story:** Lost connection to server	**Origin:** Product owner	**Dependency:**
Description: The dashboard shall show the received information even if connection to the server is lost. But interaction with the data are disabled until connection is reestablished **Rationale:** Users should still see the received information even if the connection is lost.			

ID: DQ:Rel-3	**User story:**	**Origin:** Product owner	**Dependency:**
Description: The server shall re-send messages not received by the client. **Rationale:** If the client perform aggregations of the data, it is vital that all data points exist.			

ID: DQ:Rel-4	**User story:**	**Origin:** Product owner	**Dependency:**
Description: If the connection to the server is lost. The client shall automatically reconnect. **Rationale:** No user interaction shall be required to restore a lost connection.			

ID: DQ:Rel-5	**User story:**	**Origin:** Product owner	**Dependency:**
Description: The system shall allow for scaling without large reconstruction. **Rationale:** System shall be future proof to some extent.			

B.2.6 Adaptability

ID: DQ:Ada-1	**User story:** New data sources	**Origin:** Product owner	**Dependency:**
Description: The system should have a standardized way to send data and add new sources. **Rationale:** It should be easy to add new data sources without having to modify any part of the system.			

B.2.7 Portability

ID: DQ:Por-1	**User story:**	**Origin:**	**Dependency:**
Description: The server shall run on the newest Java application servers and servlet containers. **Rationale:** Full functionality is expected to work on newest servers			

C Framework selection

There exist several frameworks that can be used for communication over WebSocket between client and server. To select the communication framework most suited for our system the following criterion was used:

- **WebSocket support** - The framework should support WebSocket by itself without any extra systems.
- **Automatic fallback** - The framework should have support for automatic fallback to another technique for communication for clients that do not support WebSocket.
- **GWT** - It is preferred if the framework has support for GWT as this is the toolkit selected to create the client.
- **JavaScript** - To support easy development of new clients for developers that do not want to use GWT or if the framework does not support GWT.
- **Multiple communication protocols** - It is better if the framework support different standards for sending and receiving messages so different types of clients and data source generators can be connected.
- **Deploy to different servlets** - The framework need to support different servlet implementations as the system should be easy to deploy on different servers.

The most popular open source alternatives found where: JBoss Errai[1], Play framework[2], CometD[3], Atmosphere[4] and jWebSocket[5]. A quick comparison between the frameworks is listed in table C.1. Standardized support for WebSocket will be available in Java EE 7 on its release in Q2 2013 (DeMichiel & Shannon 2013). As it is not yet released, it will not be taken under consideration in this thesis. As mentioned in the thesis, Spring framework is used in the system, the most convenient would be to use Spring for communication with clients as well. Unfortunately, Spring does not support WebSocket communication in the current version, 3.2. It is however under development and will most likely be supported in release 4.0 (Stoyanchev 2012).

[1] http://www.jboss.org/errai
[2] http://www.playframework.com/
[3] http://cometd.org/
[4] https://github.com/Atmosphere/atmosphere
[5] http://jwebsocket.org/

	JBoss Errai	Play framework	CometD	Atmosphere	jWebSocket
WebSocket	Yes*	Yes	Yes	Yes	Yes
Automatic fallback	Comet	No	Comet	Comet	Flash
GWT	Yes	No	Yes	Yes	Yes
JavaScript	Yes	Yes	Yes	Yes	Yes
Multiple communication protocols	No	No	No	Yes	No
Deploy to different servlets	Yes**	Yes	Yes**	Yes	No

Table C.1: Comparison of Java based WebSocket frameworks
*Not in current version of JBoss Application Server
** Not tested but should work for most servlets

C.1 Sample application

To determine which framework to use a small sample application were created in all the frameworks except jWebSockets. This was due to the fallback method, flash, which as explained in the thesis does not work on all phones and tablets.

The purpose of the sample application was to identify strengths and weaknesses of different frameworks for using the WebSocket implementations in the most common servlet containers. It was also important to see how they handled legacy clients, the publisher-subscriber pattern and their ease of use.

The application devised was a very simple one where the user selected which, of a finite amount, channels the client should subscribe to. All channels sent different information on fixed intervals and the data was displayed and continuously updated by the client.

C.2 Selected framework

JBoss Errai was not selected because WebSocket only worked when running the latest beta version of JBoss Application Server. Play framework did not support automatic fallback and since all targeted browsers do not support WebSocket, Play framework was not selected. CometD only support WebSocket when deployed on Jetty. The framework we decided to use in the system is Atmosphere since it has better support for different servlet containers and has a good implementation for GWT.

D Quantitative study

In this appendix, the configuration used in the stress test is presented. Figure D.4 is the data source used in the test. The chart configurations used can be seen in figure D.5 and D.6. The system load collected during the time series test can be found in table D.1 and for the group by test in table D.2

```
#!/bin/bash

url="http://localhost:8888/rest/client/newdata"
source="stressdata1"
sleep=$1  # sleep interval between requests

while true
do
    nameValue=$(shuf -i 97-122 -n 1)
    name=$(printf \\$(printf "%o" $nameValue))
    value=$(shuf -i 1-100 -n 1)

    curl -H "Content-type: application/json" \
      -H "Accept: application/json" \
      -k \
      --connect-timeout 5 \
      -X POST -d "{\"source\":\"$source\",\"data\":{\"name\":\"$name\",\"value\":$value}}" \
      $url &
    sleep $sleep
done
```

Figure D.1: Script used to generate events during the stress-test.

```
{
    "data":{
        "stressdata1":{
            "aggregations":[
                {
                    "fieldName":"ts_insert",
                    "name":"ts_insert",
                    "type":"value"
                },
                {
                    "fieldName":"rtt",
                    "name":"RTT",
                    "type":"value"
                }
            ]
        }
    },
    "clientToken":"StresstestSub",
    "metric":true,
    "queryType":"TIMESERIES"
}
```

Figure D.2: Time series subscription used in stress-test

```
{
    "data":{
        "stressdata1":{
            "aggregations":[
                {
                    "fieldName":"name",
                    "name":"name",
                    "type":"value"
                },
                {
                    "fieldName":"value",
                    "name":"value",
                    "type":"sum"
                }
            ],
            "dimensions":[
                "name"
            ]
        }
    },
    "clientToken":"stresstest2Sub",
    "metric":true,
    "queryType":"GROUPBY"
}
```

Figure D.3: Group by subscription used in stress-test

```
{
    "name":"Stressdata1",
    "identifier":"stressdata1",
    "priority":1,
    "columns":[
        {
            "identifier":"name",
            "name":"name",
            "datatype":"string"
        },
        {
            "identifier":"value",
            "name":"value",
            "datatype":"integer"
        }
    ]
}
```

Figure D.4: Data source used in the test

```
{
    "title":"stresstest",
    "type":"barchart",
    "dimensions":{
        "xaxis":{
            "field":"StresstestSub/stresstestdata1/ts_insert",
            "label":"Time inserted in database",
            "limit":30
        },
        "yaxis":{
            "field":"StresstestSub/stresstestdata1/value",
            "label":"Value"
        }
    }
}
```

Figure D.5: Time series chart used in latency test

```
{
    "title":"stresstest2",
    "type":"barchart",
    "dimensions":{
        "xaxis":{
            "field":"stresstest2Sub/stresstestdata1/name",
            "label":"Name",
            "limit":26
        },
        "yaxis":{
            "field":"stresstest2Sub/stresstestdata1/value",
            "label":"Value"
        }
    }
}
```

Figure D.6: Group by chart used in latency test

Clients	Message/second	Java cpu	MySQL cpu	Transmitted	Received
1	1	1.5 %	0.1 %	6.58 kbit/s	5.16 kbit/s
	10	15.78 %	0.76 %	34.22 kbit/s	26.4 kbit/s
	20	13.8 %	1.22 %	52.27 kbit/s	110.13 kbit/s
5	1	1.72 %	0.33 %	36.71 kbit/s	22.4 kbit/s
	10	12.44 %	1.58 %	210.22 kbit/s	126.76 kbit/s
	20	11.36 %	1.64 %	123.39 kbit/s	154.84 kbit/s
10	1	2.7 %	0.58 %	75.82 kbit/s	41.96 kbit/s
	10	19.1 %	2.54 %	442.84 kbit/s	252.09 kbit/s
	20	18.93 %	2.59 %	318.13 kbit/s	309.07 kbit/s
25	1	5.96 %	1.14 %	183.56 kbit/s	101.24 kbit/s
	10	40.46 %	5.56 %	1.09 Mbit/s	631.91 kbit/s
	20	35.88 %	4.84 %	663.64 kbit/s	740.27 kbit/s
50	1	9.69 %	1.97 %	366.31 kbit/s	196.98 kbit/s
	10	68.33 %	9.38 %	2.23 Mbit/s	1.35 Mbit/s
	20	58.28 %	7.94 %	1.43 Mbit/s	1.51 Mbit/s

Table D.1: Server load during time series test

Clients	Message/second	Java cpu	MySQL cpu	Transmitted	Received
1	1	0.56 %	0.13 %	5.87 kbit/s	10.31 kbit/s
	10	5.14 %	1.3 %	33.24 kbit/s	103.29 kbit/s
	20	10.63 %	3.14 %	62.58 kbit/s	193.6 kbit/s
	80	32.42 %	23.4 %	237.87 kbit/s	736.98 kbit/s
5	1	2.01 %	0.24 %	37.24 kbit/s	27.11 kbit/s
	10	15 %	2.42 %	351.82 kbit/s	323.64 kbit/s
	20	21.6 %	5.08 %	536.8 kbit/s	720 kbit/s
	80	46.73 %	24.32 %	670.67 kbit/s	2.21 Mbit/s
10	1	1.99 %	0.37 %	62.4 kbit/s	63.73 kbit/s
	10	19.17 %	3.6 %	574.58 kbit/s	758.76 kbit/s
	20	36.84 %	7.39 %	1.08 Mbit/s	1.43 Mbit/s
	80	70.64 %	25.92 %	1.62 Mbit/s	4.39 Mbit/s
25	1	4.87 %	0.8 %	194.4 kbit/s	251.73 kbit/s
	10	40.22 %	6.49 %	1.46 Mbit/s	1.74 Mbit/s
	20	74.44 %	12.78 %	2.93 Mbit/s	3.29 Mbit/s
	80	104.21 %	29.59 %	3.48 Mbit/s	10.3 Mbit/s
50	1	8.3 %	1.43 %	356.53 kbit/s	480.62 kbit/s
	10	68.78 %	10.31 %	2.94 Mbit/s	3.58 Mbit/s
	20	123.36 %	19.1 %	5.76 Mbit/s	6.75 Mbit/s
	80	55.18 %	21.58 %	3.34 Mbit/s	11.16 Mbit/s

Table D.2: Server load during group by test